

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 4033

SCREEN-TYPE NOISE REDUCTION DEVICES FOR GROUND RUNNING OF TURBOJET ENGINES

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SUMMARY

The previously reported (NACA TN 3452) advantages of screens placed across the jet as a means of suppressing jet noise during ground running were somewhat offset by increased noise levels ahead of the engine. This disadvantage has been overcome by a combination screen and muffler which effectively eliminates these increases and gives substantial additional suppression throughout the sound field. Maximum sound pressure levels at 200 feet were reduced to 104 decibels (a 16-db reduction), and the over-all sound power was reduced by 12 decibels. Reductions of at least 4 decibels and as much as 17 decibels were obtained in the spectrum power levels.

Air-jet tests showed negligible reduction in sound generation with additional screens. Both air-jet and engine tests showed airfoil-vane jet diffusers to be less effective than screens.

The large reductions obtained by using screens show that noise generated inside the engine (nonafterburning) by the turbine or by combustion contribute only a minor part of the total noise.

INTRODUCTION

Jet-engine-noise reduction has been the subject of much research and development work. One of the major problems is that associated with ground runup during operational checks or other engine tests. Military airfields and naval aircraft carriers are faced with this noise problem, and, as commercial jet transport aircraft become more numerous, many additional airports and communities will be affected. Standard acoustic techniques have been successfully applied to test cells, and runup pens have been proposed and built for aircraft. Nearly all the successful muffling devices, however, are large, heavy, expensive, and at best only slightly portable.

References 1 and 2 have shown that screens located transversely across the jet offer considerable noise reduction and are of much smaller and lighter construction and, consequently, are less expensive than most mufflers. The screen is effective in reducing the noise level because it diffuses the jet to a larger stream at correspondingly less velocity. The screen-type noise suppressor is not intended for use during flight because of the large pressure loss through the screen which is in effect the drag of the screen and which may be more than half the thrust of the engine. However, since this device, when properly spaced, causes no impairment of engine operation, it might conceivably be attached to the catapult shuttle on an aircraft carrier.

The full-scale engine tests reported in reference 2 showed impressive noise reductions and indicated optimum screen wire size and mesh and location downstream of the jet exit. The investigation also showed that certain combinations of screen location and engine power resulted in undesirable resonance conditions. In addition, increases (particularly at the higher frequencies) in the noise forward of the engine while using the screens indicated that the high-frequency noise was primarily being generated in the region between the engine exit and the screen or by the vibration of the screen itself. A screen spacing downstream of the jet exit of at least 0.33 nozzle diameter was required to eliminate any restriction of the flow at the nozzle. It appeared that a shield or sound absorber or both surrounding the region between the engine and screen would aid in suppressing the noise radiated forward from either cause. A preliminary report of this work was made in reference 3. The possibility of obtaining further noise reduction by means of multiple screens and through the use of airfoil sections instead of screen wire to provide the jet diffusion also warranted investigation. Under certain conditions, wire shape (ref. 4) has considerable effect upon noise generation caused by airflow over the wires. Thin airfoil shapes were found to delay the onset of high noise levels at discrete frequencies (ref. 4).

Therefore, this investigation determines the feasibility of several devices which might improve upon the characteristics of the screen-type noise suppressor. Some of the devices were investigated using an engine, and some were studied with a 4-inch-diameter air jet. The investigation was performed at the NACA Lewis laboratory.

APPARATUS AND PROCEDURE

Air-Jet Facility

The heated air-jet facility previously used in an investigation of the far-noise field of jets (refs. 5 and 6) and shown in figure 1 was used to study several of the suppressor configurations. Cold air or air heated to a temperature of 200° F was supplied to the 4-inch-diameter

nozzles at pressure ratios (jet total to ambient static) near 2.0 which corresponds to the usual jet takeoff condition. The air supply system contained pressure, temperature, and airflow measurement and control equipment. In addition, the diffuser section immediately upstream of the plenum tank was equipped with screens, and the inlet to the nozzle was a large bellmouth to give good flow characteristics at the nozzle. Mufflers were included in a section of the pipe downstream of all elbows, orifices, and valves, and the air was supplied from remotely located compressors; this ensured a minimum of extraneous noise being transmitted down the pipe.

Air-Jet Noise Suppression Devices

The air-jet nozzle, screen support, and screen assembly are shown in figure 2. The screen holders could be positioned at any point along the support tubes. Four screens, two 4-mesh, 0.047-inch-diameter wire and two 8-mesh, 0.036-inch-diameter wire, were used. The solidity (ratio of blocked area to total area) of the screens was 0.38 and 0.58, respectively, for the 4- and 8-mesh screens. In addition, an airfoil-vane-type jet diffuser (fig. 3) which fitted on the same support assembly was used. The vanes were symmetrical $1\frac{1}{2}$ -inch-chord airfoils and had a thickness-to-chord ratio of 0.12. The airfoil separation was varied by means of spacers.

Full-Scale Engine Facility

The equipment used for the engine tests is essentially that described in reference 2. The engine is an axial-flow turbojet engine having a sea-level rated thrust of 5000 pounds at a turbine-outlet temperature of 1275° F. Under these conditions the exhaust total- to static-pressure ratio is approximately 1.7. Engine airflow and fuel flow were measured for each condition.

Full-Scale Noise Suppression Devices

The photograph and sketch presented in figures 4(a) and (b) show the engine and screen-and-muffler assembly. The $1/4$ -inch wire diameter, 1-inch-mesh screen was combined with a sheet-steel annular shield having a 4-inch glass-fiber inner liner held in place with a commercially obtained perforated metal acoustical panel. The perforated panel was zinc-coated and had 3600 holes of $1/16$ -inch diameter per square foot of panel. An annular end piece of the same construction and having an inside diameter approximately 3 inches larger than the engine tailpipe diameter completed the assembly. The screen-and-muffler assembly was fitted

around the engine tailpipe with the nozzle exit approximately 12 inches from the screen. Reference 2 shows that the 12-inch dimension would give satisfactory noise reduction with no back-pressure effects on the engine.

In order to obtain the diffusion of the stream with airfoil-shaped vanes in place of the screen wires, the vane jet diffuser shown in figure 5 was used with the engine. The vanes were of symmetrical airfoil shape with a 6-inch chord length and had a thickness-to-chord ratio of 0.08. The spacing between the vanes could be changed, which allowed a change in the solidity of the device.

The airfoil vanes consisted of 3/8- by 3/4-inch steel spars covered with a 1/16-inch sheet-steel skin. The vanes were not restrained longitudinally in the frame to allow for thermal expansion. The localized heating and the restraining effect of the bars inside the vanes caused considerable warpage of the leading and trailing edges of the vanes after relatively short periods of engine operation.

ACOUSTIC MEASUREMENTS

Acoustic Terms and Instrumentation

The acoustic terms used herein are those defined in reference 7. Sound pressure level in decibels is based on a reference pressure of 0.002 dyne per square centimeter, and sound power level is based on a reference power of 1×10^{-13} watt. Sound pressure level measurements were made with a commercial sound level meter. Frequency distributions were measured with an one-third octave band audiofrequency analyzer and automatic recorder. This unit was mounted in an acoustically insulated truck, and direct field records were obtained. Before each test, both the sound level meter and the frequency recorder were calibrated with a small loudspeaker-type calibrator and transistor oscillator. Additional information on the instrumentation is given in references 2 and 5.

Air-Jet Sound Field

The acoustic measurements for the air jet were made at 15° intervals at 25- and 50-foot radii. Fifteen measurement stations were located on each arc and extended from 120° from the jet direction on one side to 90° from the jet direction on the other as shown in the plan view sketch of figure 6. Also shown are the relative positions of the nearby buildings.

Engine Sound Field

The sound field surrounding the engine was essentially free of reflecting surfaces other than the ground (concrete and turf). The nearest large building was 500 feet away and in front of the engine. Acoustic measurements were made at a radial distance of 200 feet about the engine exhaust exit in 15° intervals over a 270° sector as shown in figure 7. No acoustic measurements were made in the quadrant in which the engine control building was located.

Measurements

Spectra were measured at one radial distance only (50 ft for the air jet and 200 ft for the engine). The spectral distribution was measured for the air jet at 30° and 90° from the jet axis and for the engine at all stations on one side of the engine.

Calculations of the total sound power radiated from the jets were made using the integration process from the sound pressure level measurements as described in reference 2. The same procedure was applied to the sound pressure levels obtained for each one-third octave band of frequencies from the frequency analyzer data to give the frequency distribution of the sound power.

No tests were made when the wind velocity was greater than 12 to 14 miles per hour. Tests made on different days with the same nozzle showed local sound pressure level variations as high as ± 3 decibels because of displacement of the jet due to the wind. The sound power variation, however, was less than ± 1 decibel as the integration process tends to average out errors in local values.

RESULTS AND DISCUSSION

Air Jet

Single screen. - A polar diagram (directionality pattern) of the sound pressure levels obtained with a 4-mesh screen (solidity, 0.38) mounted at two distances from the air-jet nozzle exit is presented in figure 8(a). Included for comparison are the polar diagram for the air jet without a screen and the over-all sound power level values. The figure shows that both screen locations reduced the sound power approximately 4 decibels. Differences due to the screen location were slight. The spectral distributions of the noise at the 30° azimuth for the same configurations are presented in figure 8(b) and show the large reductions obtained in the middle frequencies with the use of screens. A slight increase in level at high frequency (above 4000 cps) occurs for both screen positions.

Multiple screen. - The results obtained with the multiple screen configurations are shown in figure 9. Several combinations of screen mesh and distance from the nozzle are compared with the results obtained with no screen. The directionality patterns (fig. 9(a)) are quite similar for all the screen combinations. With the screens mounted at the minimum distance from the nozzle the sound pressure level at the side of the jet is reduced. The sound power level for all configurations was reduced 3 to 6 decibels from that obtained with no screen. A comparison of figures 8(a) and 9(a) shows that the sound power for the multiple screen was about the same as that for the single screen. The spectrum level at the 30° azimuth is shown in figure 9(b). The frequency distribution is quite similar for all the screen configurations, and all show considerable reductions (up to 30 db) in the middle frequency range (100 to 2000 cps). Slight increases in spectrum levels were again found at frequencies above 4000 cycles per second.

Airfoil diffuser. - The jet diffuser with the airfoil vanes was investigated at two values of solidity and at two pressure ratios for two distances of the diffuser from the nozzle exit.

A preliminary check using cold air and three locations of the diffuser (vane leading edge $1/2$, 1, and 2 in. downstream of the nozzle exit) showed that as the distance was increased to 2 inches the sound levels were as high as those for the standard nozzle at the downstream azimuths and up to 5 decibels higher than the standard nozzle at the sides. Succeeding tests were made using heated air and only the $1/2$ - and 1-inch downstream locations. Heating the air reduces condensation and for a given pressure ratio gives higher jet velocity with consequent higher sound pressure levels.

Figure 10 presents the results obtained with heated air at a pressure ratio of 2.0 using the airfoil diffuser with a solidity of 0.385. The directionality patterns are shown in figure 10(a), and the spectrum levels at two azimuths are shown in figures 10(b) and (c). The acoustic characteristics for similar conditions, but with the vanes positioned to give a solidity of 0.51, were similar to those presented in figure 10 for the solidity of 0.385. In general, somewhat higher noise levels were obtained at the side of the jet, and, consequently, there was little, if any, reduction in sound power from the standard. This trend was even more pronounced at the lower pressure ratio (1.86).

Figure 10(a) shows that the diffuser position nearest the nozzle (max. thickness section of vane chord approx. 0.33 nozzle diam. downstream) gave the least value of sound power. For the vane solidity of 0.385 (fig. 10) reductions in the maximum sound pressure level of approximately 11 decibels were achieved at the 15° azimuth. The reduction in sound power is much less because of increased levels at the sides of the jet.

The spectral distribution of sound was quite similar at corresponding azimuths for both pressure conditions, and the diffuser spacing and solidity had minor effects. In general, the spectra show a shift to the higher frequencies with reductions over the entire range to about 3000 cycles per second at the 30° azimuth. Little or no change is shown at the 90° azimuth except for the increase at the higher frequencies.

Engine

Screen and muffler. - The effectiveness of the screen and muffler is shown in figures 11(a) to (e) which compare the results obtained with the previous screen results and the standard configuration (no screen). Figure 11(a) presents the directionality patterns and the over-all sound power. At the point in the sound field where the sound pressure level was a maximum, a reduction of approximately 16 decibels in sound pressure level was obtained with the screen and muffler. The previous work with the screen alone showed large increases in the sound forward of the engine. With the screen and muffler the noise forward of the engine was approximately 6 decibels less than that for the standard configuration and up to 18 decibels less than that for the screen alone.

The maximum sound pressure level recorded with the screen and muffler was 104 decibels. The reduction in total over-all sound power from 4020 to 254 watts represents a 12-decibel decrease by use of the screen and muffler. These were the most important results obtained in this investigation. An additional important conclusion that can be determined from figure 11(a) is that the combustion or turbine noise generated inside the engine can only be a small part of the total. Such noise would pass through the screen essentially undiminished, and hence the sound pressure levels must be as low as those shown on figure 11(a) for the screen configuration (12 db less than the jet noise for the standard configuration for azimuths to 35°).

Spectrum level distributions at three azimuths (30°, 90°, and 180° from the jet centerline) are shown in figures 11(b) to (d). At the 30° azimuth the screen alone and the screen-and-muffler combination show similar reductions at frequencies below 250 cycles per second (fig. 11(b)). From 250 to 10,000 cycles per second the screen-and-muffler combination shows additional 2- to 9-decibel reductions. The data obtained at the 90° azimuth show moderate reduction at the lower frequencies and considerable reduction in the range from 2500 to 5000 cycles per second (fig. 11(c)). Forward of the engine the previous screen results had shown large increases in spectrum level at frequencies above 200 cycles per second (fig. 11(d)). With the screen-and-muffler combination the noise forward showed decreases over almost the entire frequency range and showed large reductions from the screen-alone results above 200 cycles per second.

Figure 11(e) shows the spectrum power level distribution for the screen-and-muffler and the standard configurations. The screen-and-muffler results are a minimum of 4 decibels less than those of the standard configuration and in the middle frequency range (150 to 400 cps) show reductions of as high as 17 decibels. No study was made of the minimum size of an effective screen-and-muffler combination, but the unit probably could be smaller.

Airfoil jet diffuser. - Sound polar diagrams of the sound field for the engine using the airfoil-vane jet diffuser are shown in figure 12. The effects of diffuser position, diffuser solidity, and engine speed are shown. Approximately 9-decibel reductions were obtained at the maximum sound pressure level positions (30° from the jet axis). Little or no change from the standard was exhibited from the 60° azimuth forward. The reductions rearward are not sufficient to qualify this device as a good suppressor, and the warpage of the vanes further detracts from its usefulness.

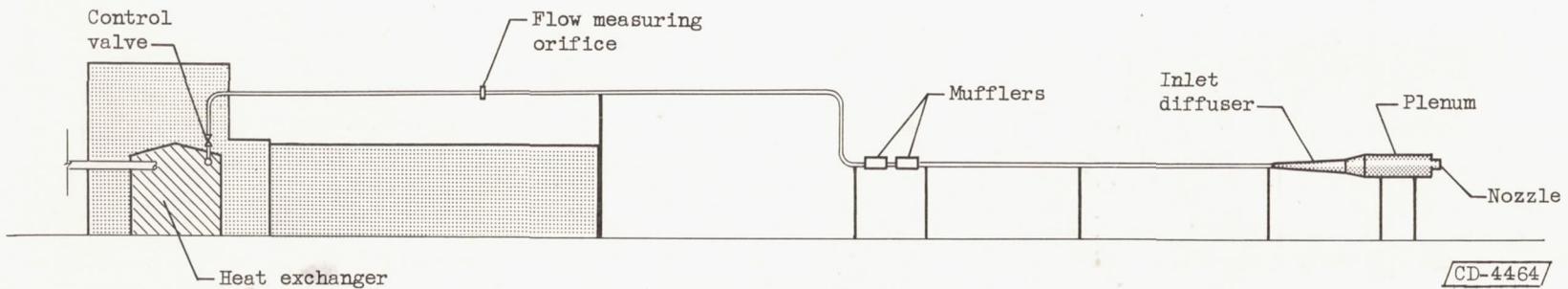
SUMMARY OF RESULTS

The following results were obtained from a study of several possibilities for improvement of the noise suppression of the screen-type suppressor:

1. The use of a combination sound shield and sound absorber in conjunction with a screen across the engine exhaust provided excellent noise reduction at all points in the sound field. The maximum sound pressure level measured was 104 decibels, compared with almost 120 decibels for the engine alone. Engine operation was unimpaired.
2. The total over-all sound power of the engine was reduced 12 decibels by the use of the screen and muffler. Reductions of at least 4 decibels and as high as 17 decibels were obtained in the spectrum power levels. The largest reductions were in the 150- to 400-cycle-per-second range.
3. Air-jet tests showed negligible improvement in noise reduction with multiple screens as compared with single screens.
4. Both air-jet and engine tests with airfoil-vane diffusers showed less noise reduction than was obtained with screens.
5. The large reduction in engine noise obtained with the screen-and-muffler combination and the screen alone demonstrates the minor contribution of combustion and turbine noise.

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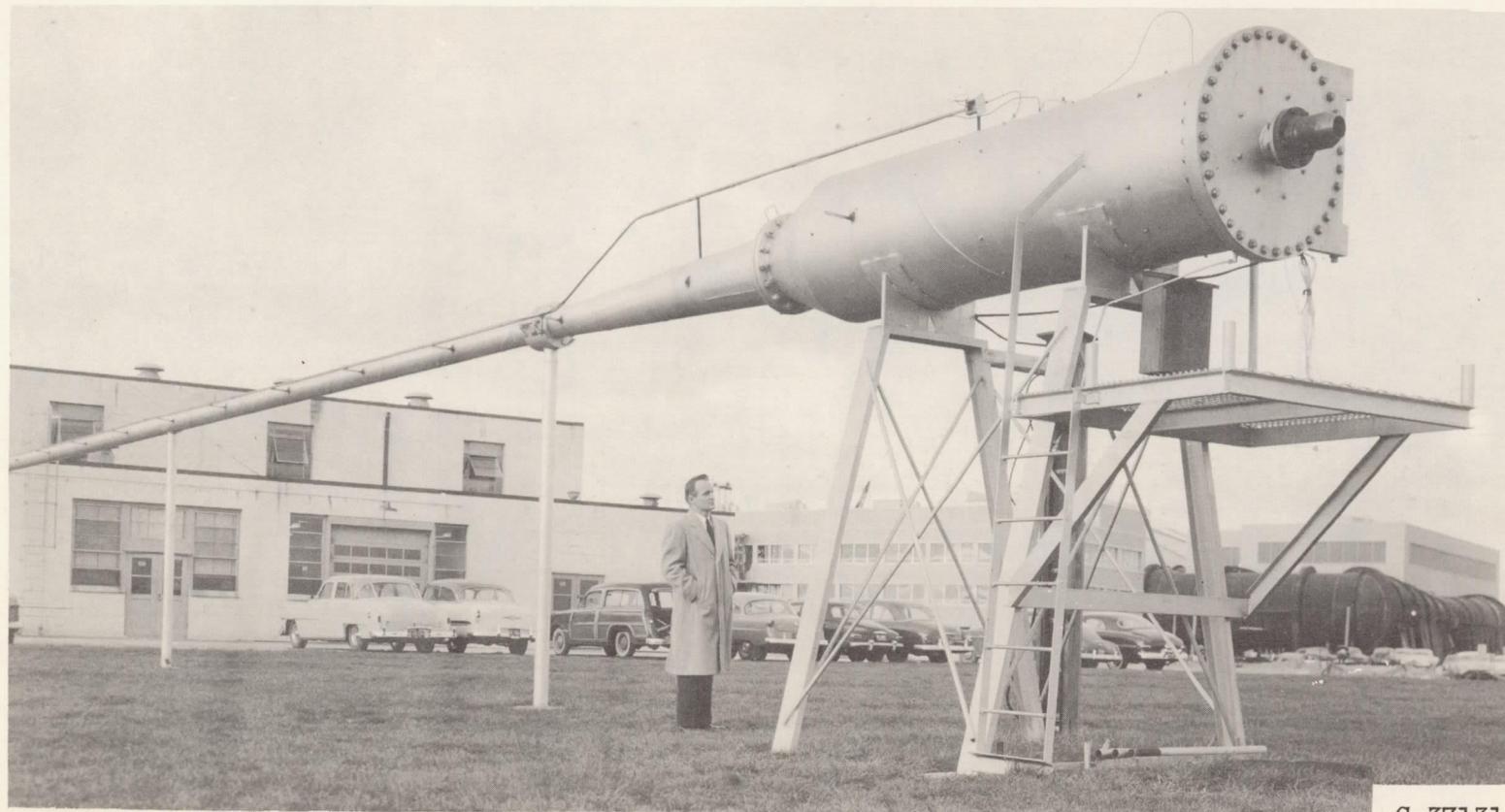
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(a) Elevation; side view.

Figure 1. - Air-jet facility.

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(b) Nozzle, plenum chamber, and associated piping.

Figure 1. - Concluded. Air-jet facility.

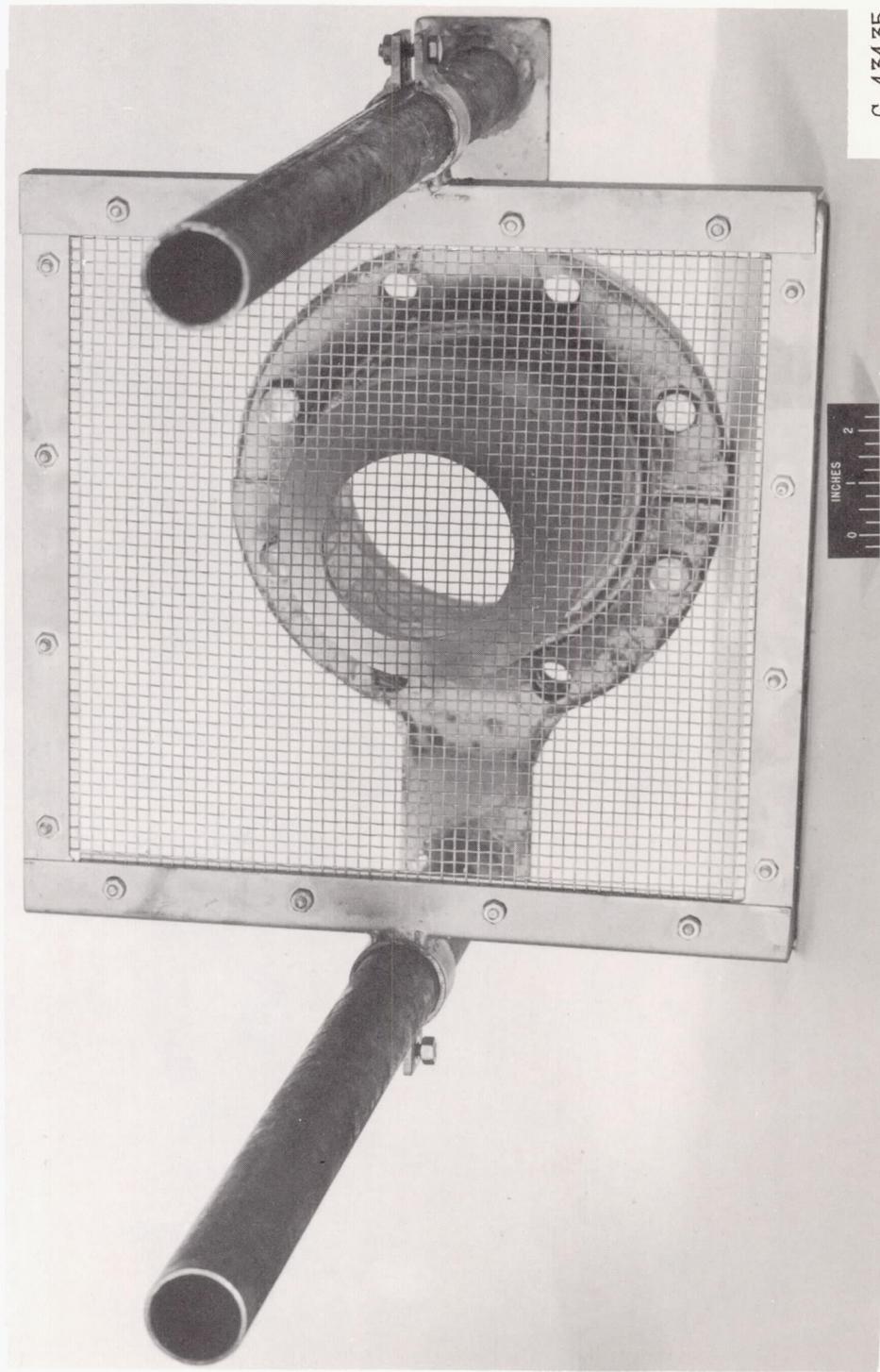
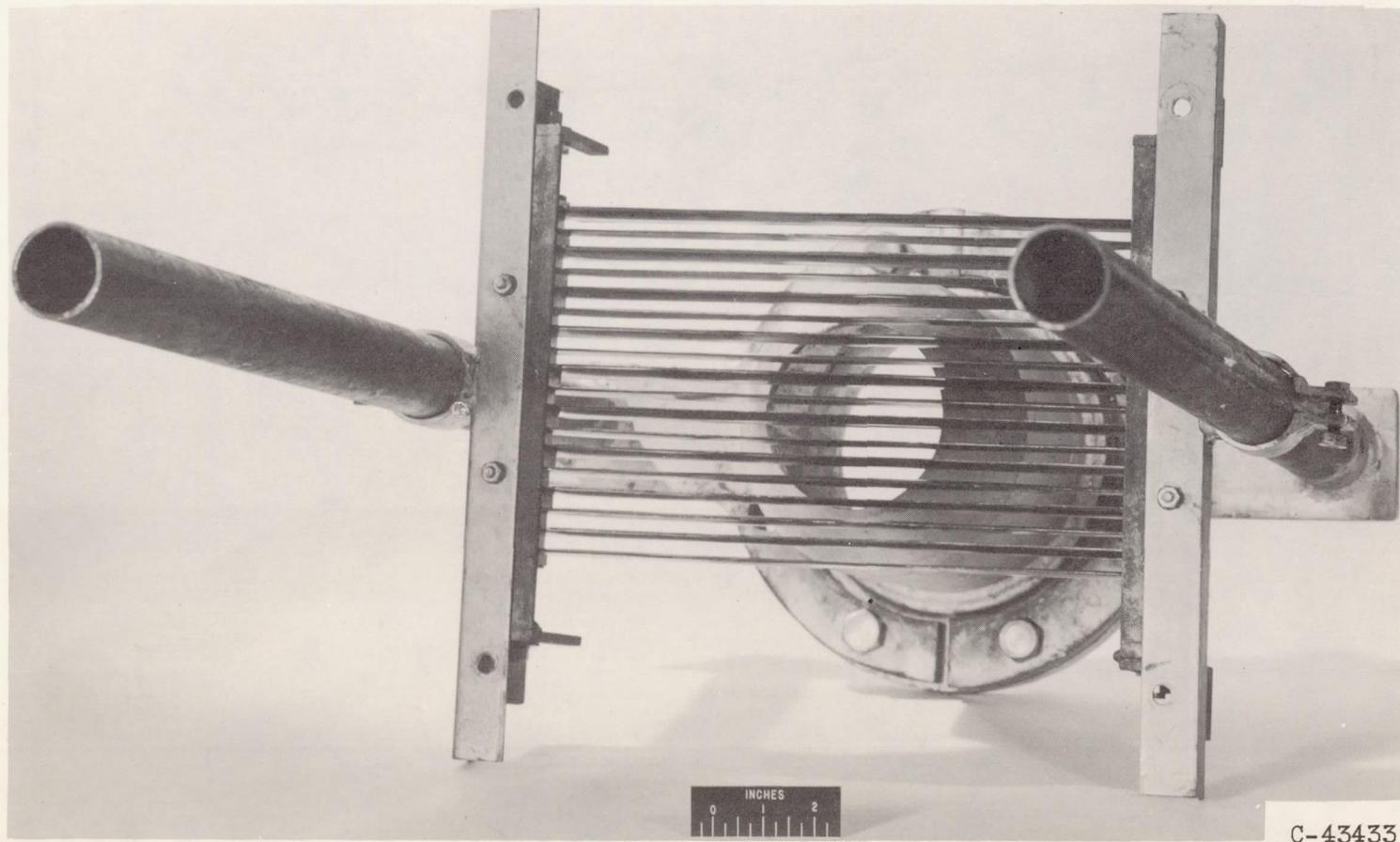
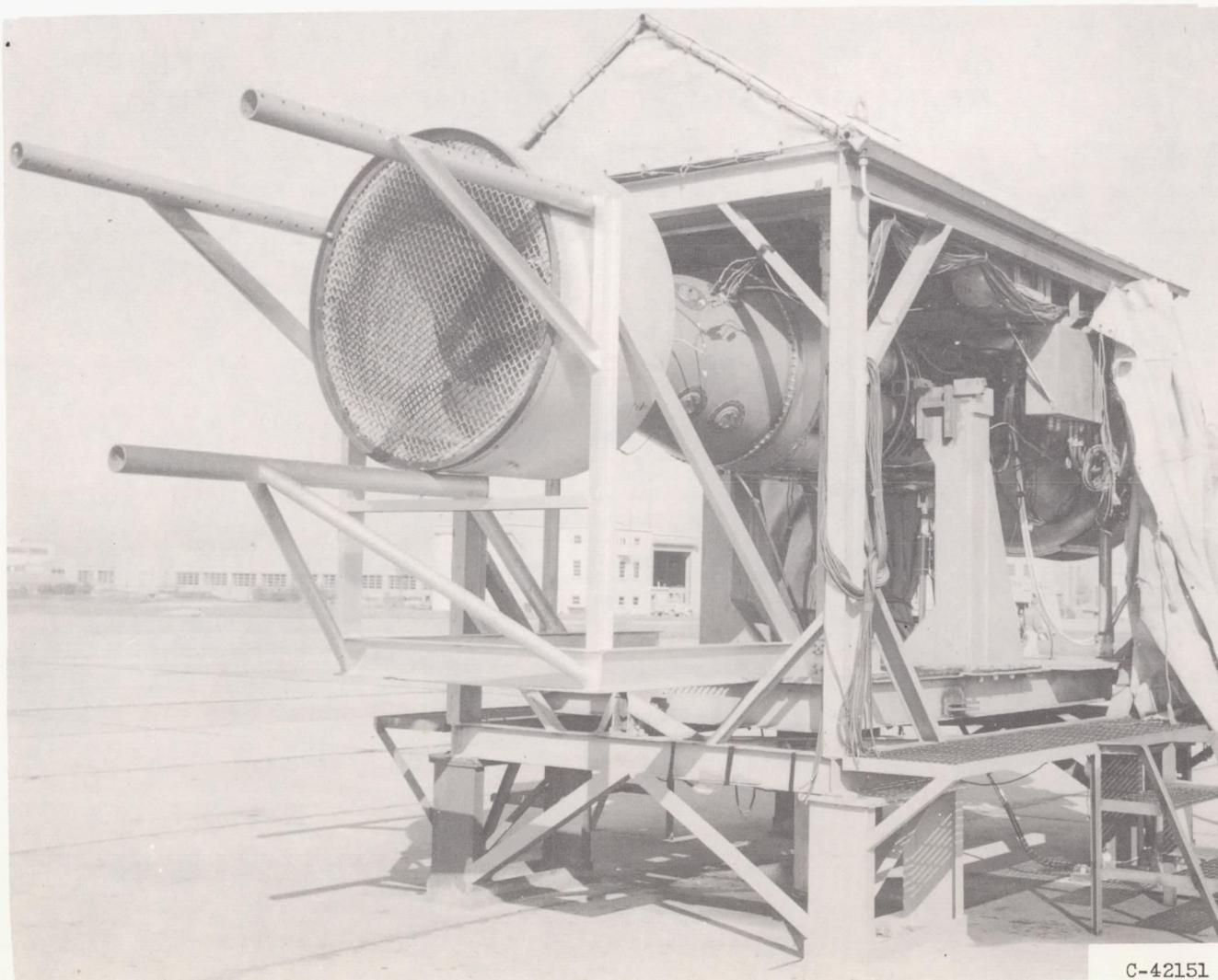


Figure 2. - Air-jet nozzle, screen support, and screen assembly.



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Figure 3. - Air-jet nozzle and airfoil-vane jet diffuser.

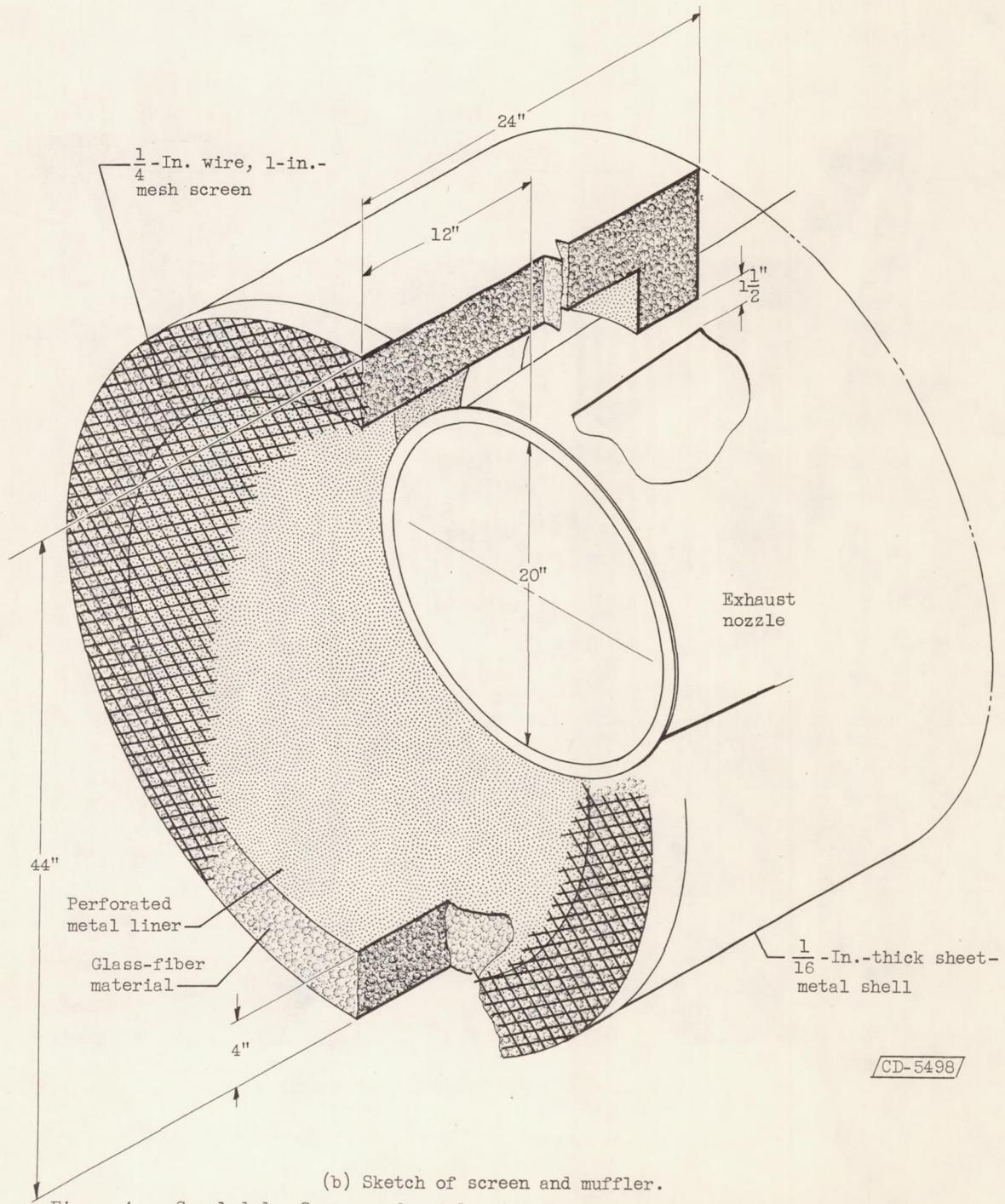


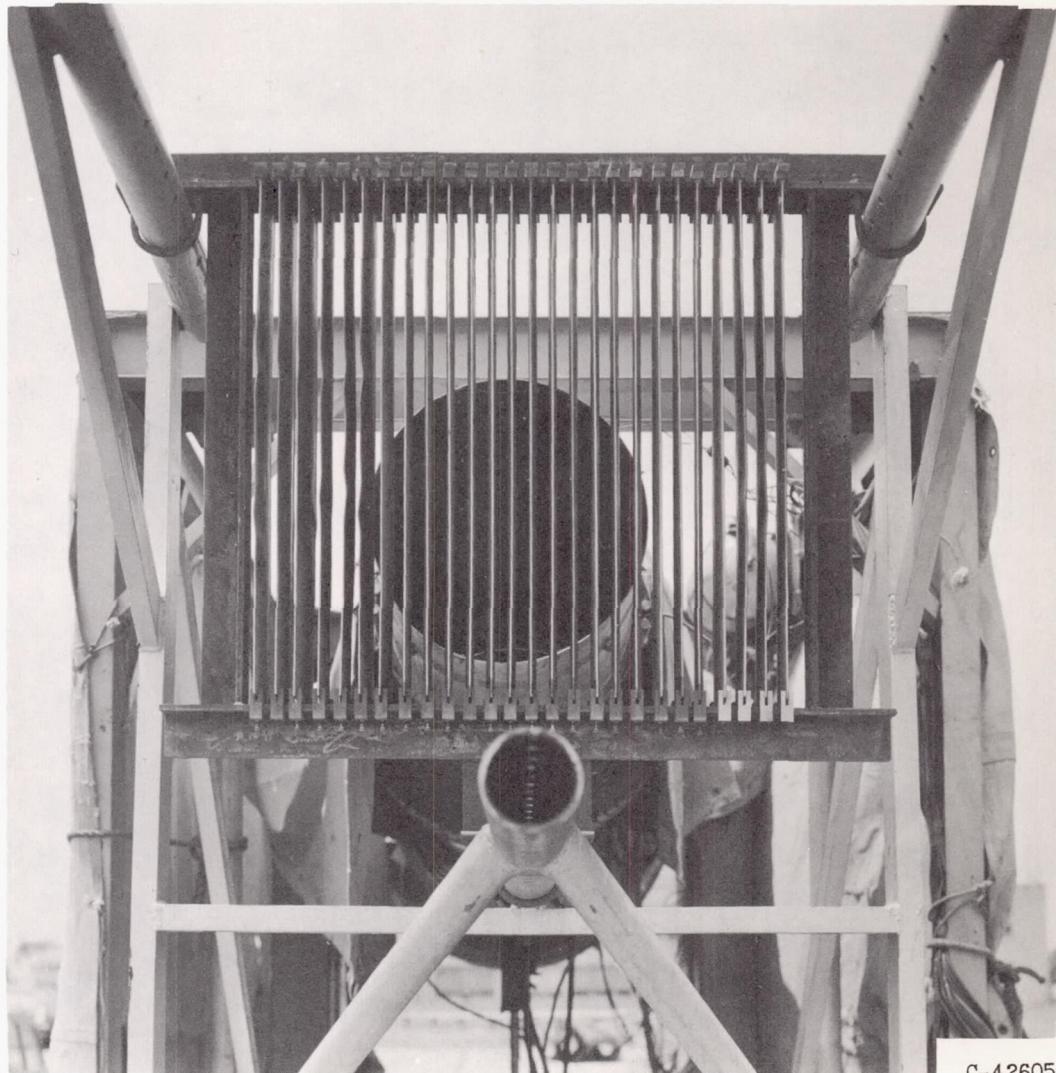
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(a) Screen and muffler, engine, and thrust stand.

Figure 4. - Screen and muffler for jet-engine-exhaust noise suppression.

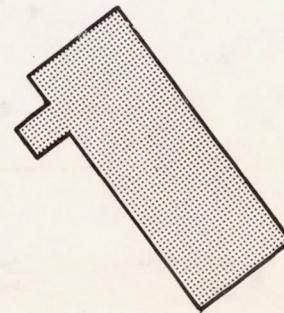
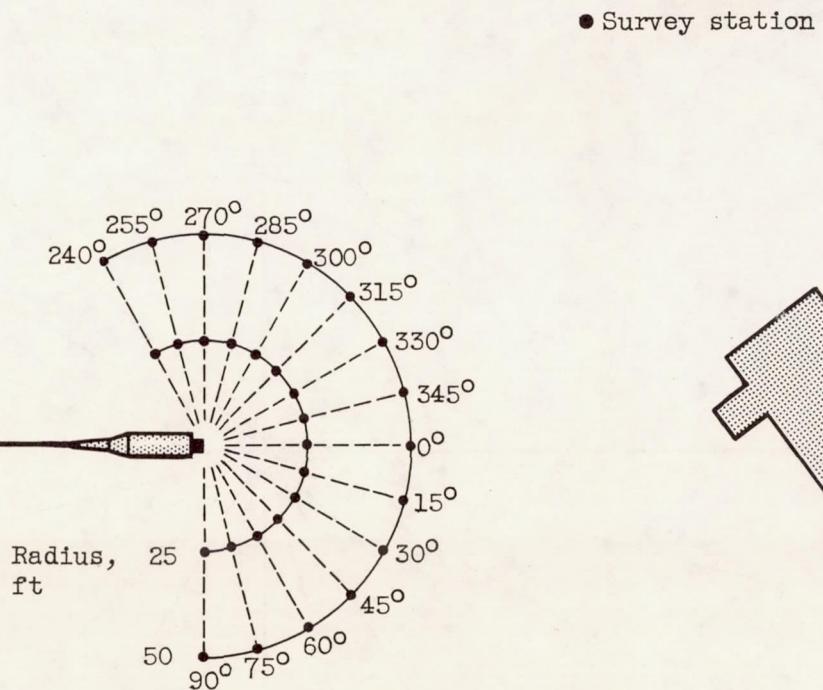
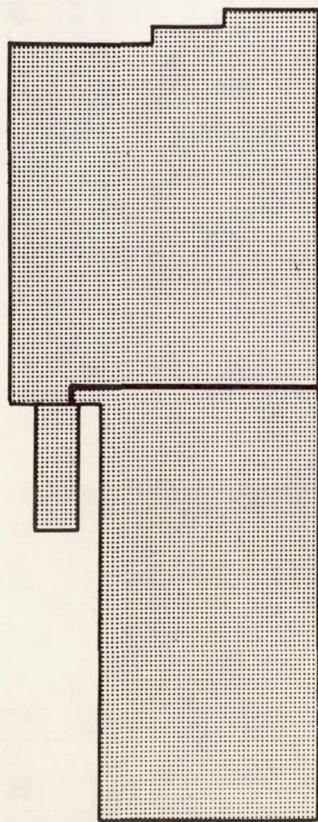
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Figure 5. - Airfoil-vane jet diffuser.



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Figure 6. - Plan view diagram of air-jet system and adjacent buildings.

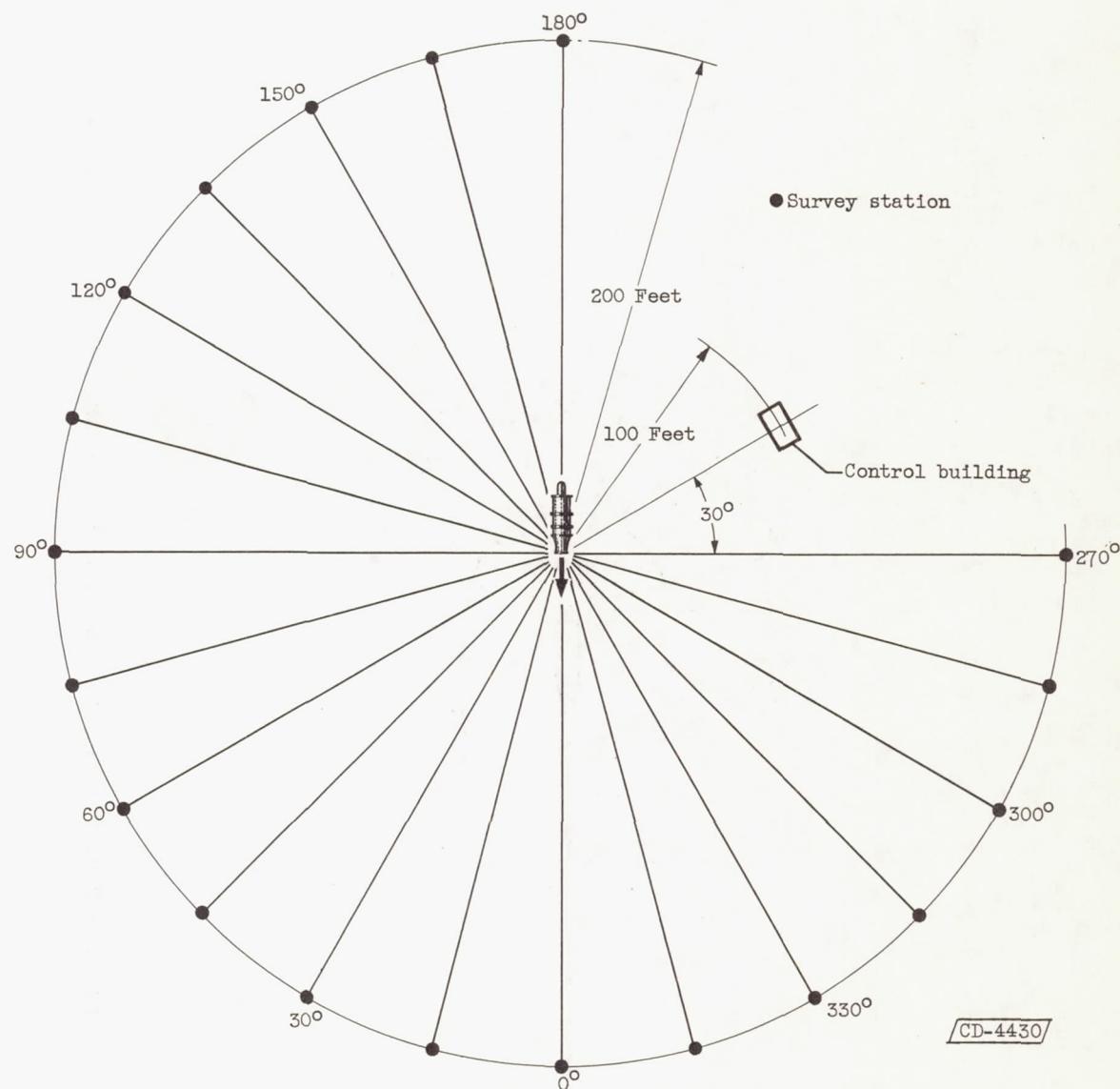


Figure 7. - Plan view of engine sound survey stations and control building.

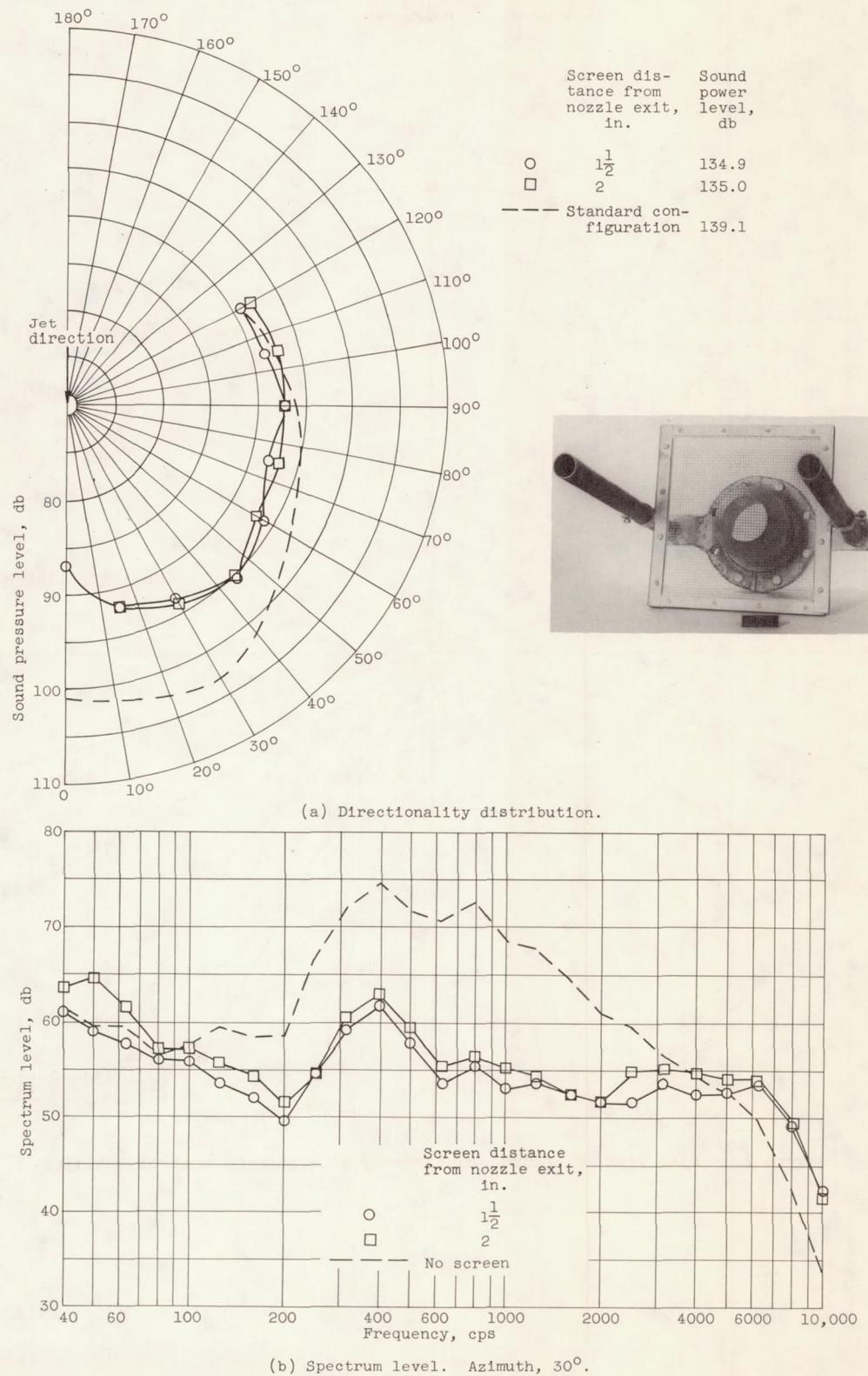
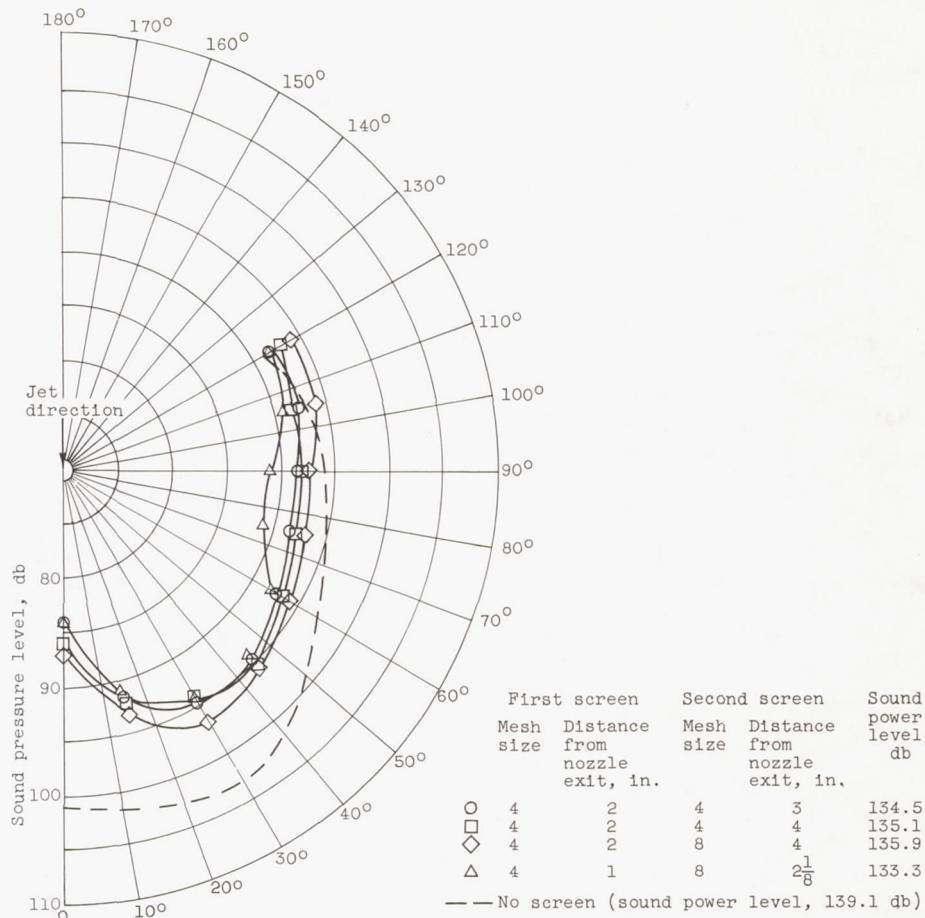
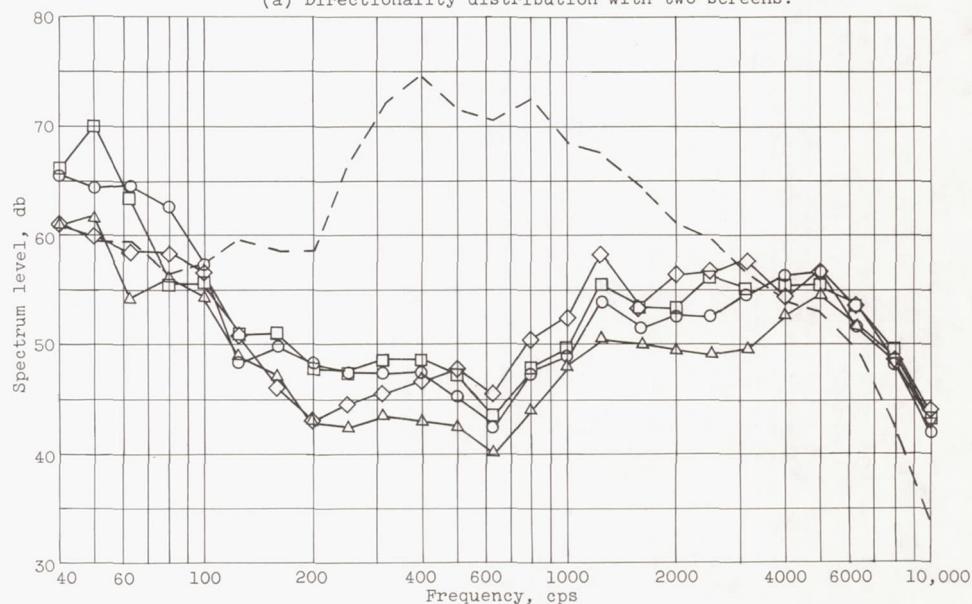


Figure 8. - Acoustic characteristics of 4-inch-diameter air jet with single screen at two distances from nozzle exit. Pressure ratio, 2.0; distance from nozzle exit, 50 feet; 4-mesh screen; cold air.



(a) Directionality distribution with two screens.



(b) Spectrum level for several multiple screen configurations. Azimuth, 30°.

Figure 9. - Acoustic characteristics of 4-inch-diameter air jet with various screen configurations. Pressure ratio, 2.0; distance from nozzle exit, 50 feet; cold air.

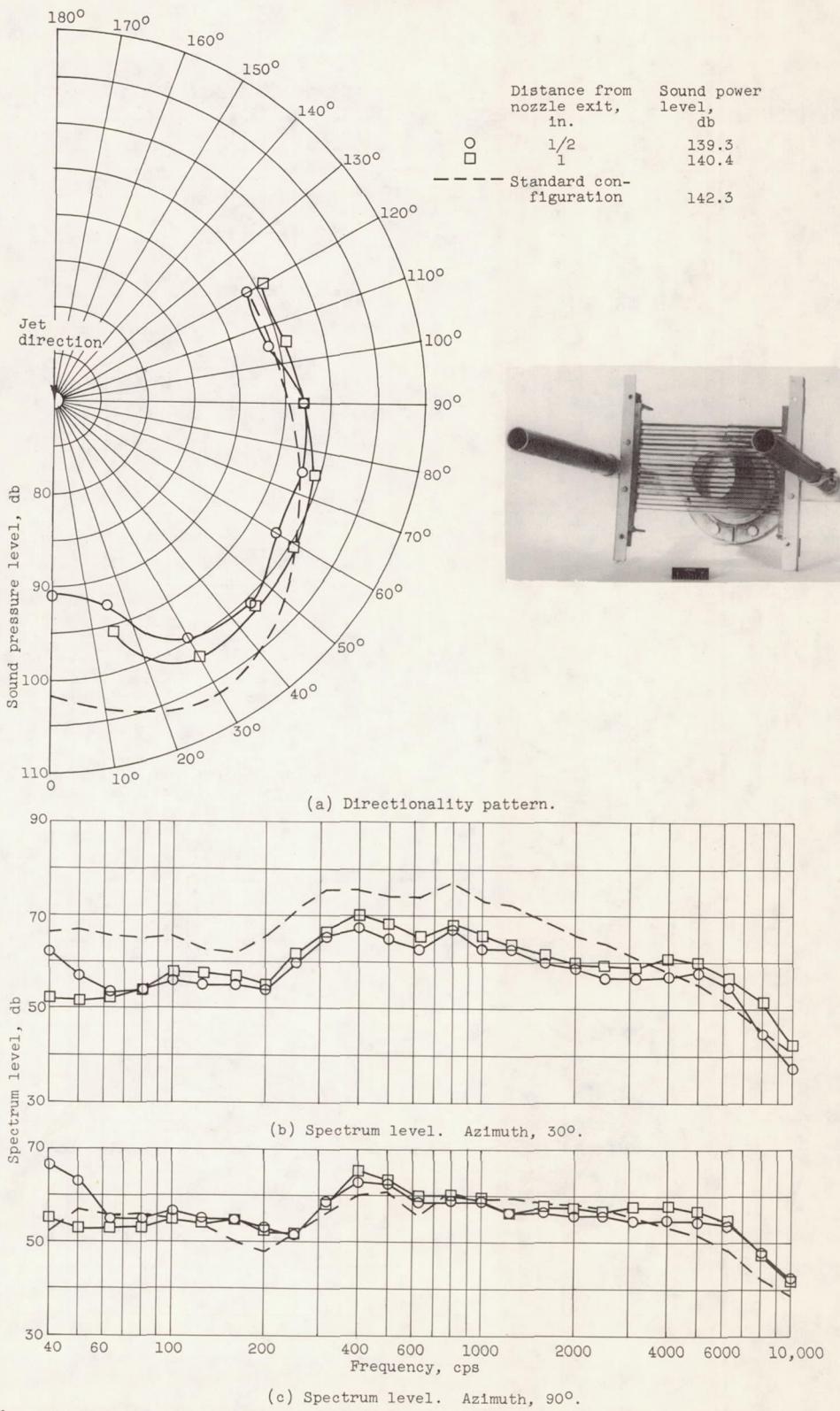


Figure 10. - Acoustic characteristics for airfoil diffuser. Air temperature, 200° F; solidity, 0.385; pressure ratio, 2.0; distance from nozzle exit; 50 feet.

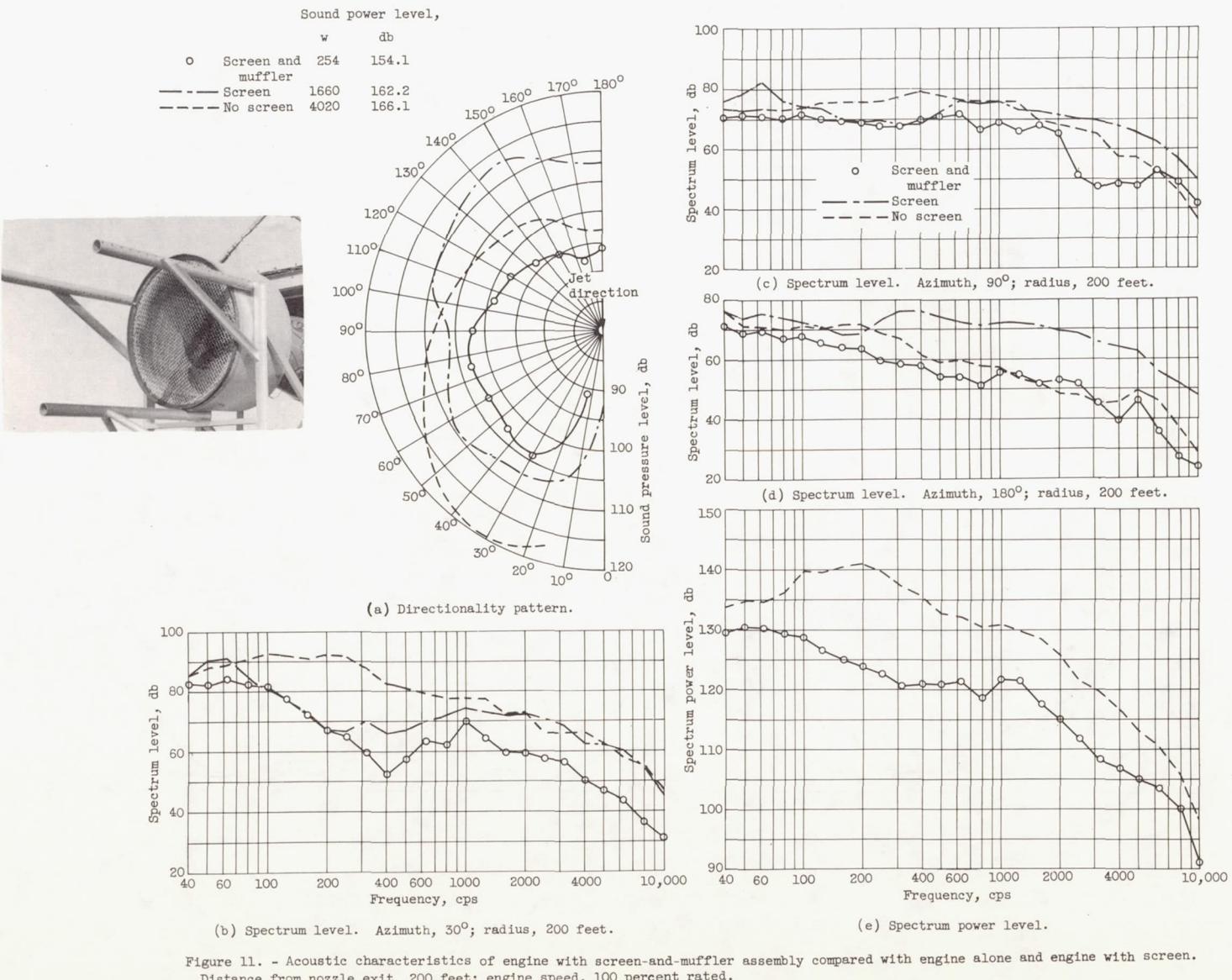


Figure 11. - Acoustic characteristics of engine with screen-and-muffler assembly compared with engine alone and engine with screen. Distance from nozzle exit, 200 feet; engine speed, 100 percent rated.

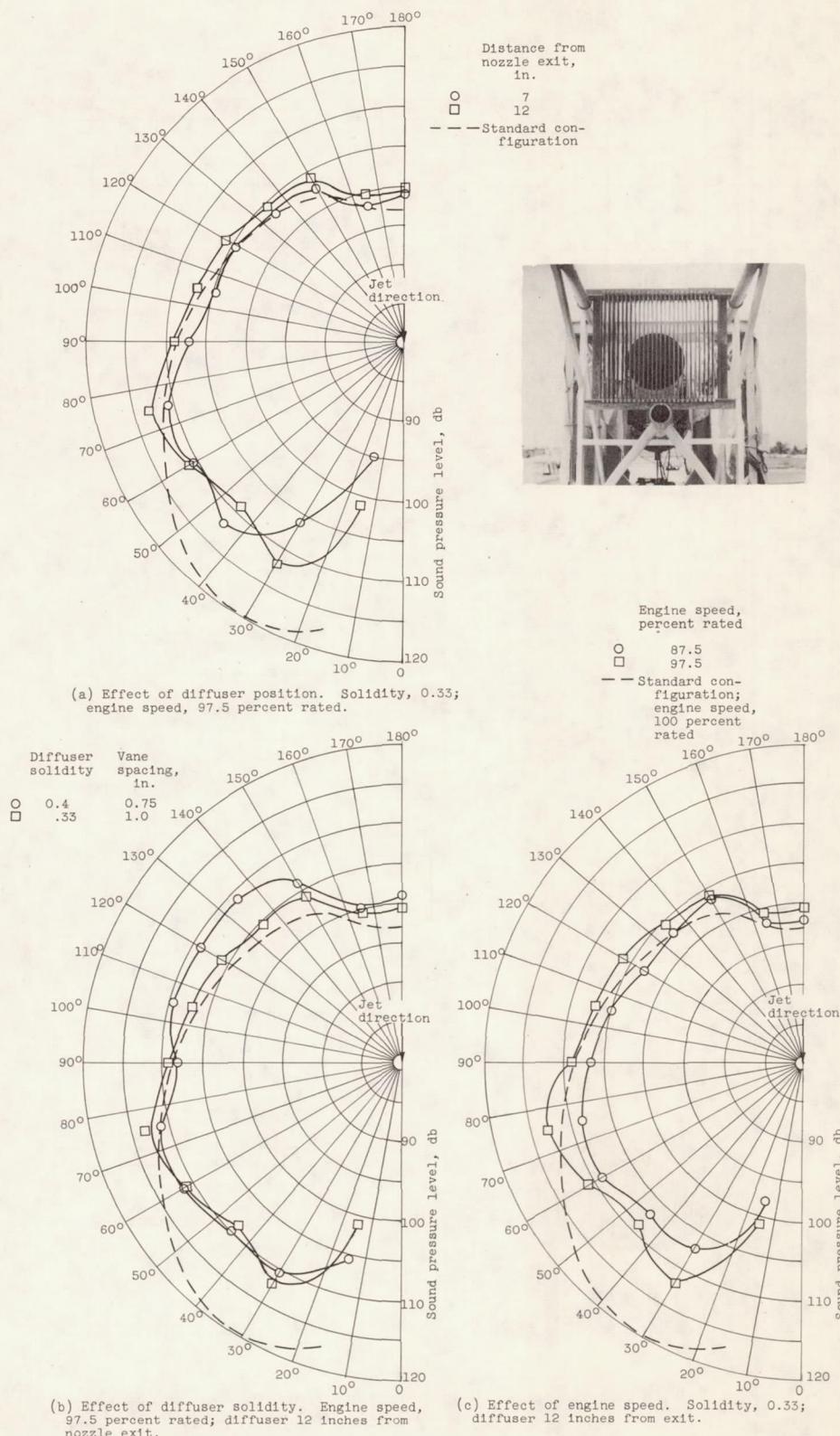


Figure 12. - Sound polar diagrams for engine using airfoil jet diffuser.
Distance from nozzle exit, 200 feet.